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Braak, S.W. van den; Oostendorp, H. van; Prakken, H.; Vreeswijk, G.A.W.

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Representing narrative and testimonial knowledge in sense-making software for crime analysis

Susan W. VAN DEN BRAAK ^{a,1}, Herre VAN OOSTENDORP ^a,
Henry PRAKKEN ^{a,b} and Gerard A.W. VREESWIJK ^a

^a *Department of Information and Computing Sciences, Utrecht University*

^b *Faculty of Law, University of Groningen*

Abstract. In the *AVERs* sense-making tool for crime analysis different types of information are represented in different ways. More precisely, narrative knowledge is represented in an explanatory direction and testimonial knowledge in an indicative direction. This paper shows that this distinction agrees with the preference of potential users and reduces the number of interpretation errors made by them.

1. Introduction

Recently, we proposed the *AVERs* (Argument Visualization for Evidential Reasoning based on stories) sense-making system for crime analysis, in which crime analysts can manage and visualize the information available in a case and express the reasons why certain pieces of evidence support or attack a certain hypothesis [1]. More precisely, in *AVERs* two kinds of knowledge about a case can be expressed, namely, ‘narrative’ and ‘testimonial’ knowledge. The former contains elements that are used to construct stories about what happened. The latter consists of information from testimonies, but also from other evidential documents, which is used to support the elements of these stories.

While devising such a sense-making tool, a choice has to be made regarding how the different types of knowledge should be represented, since both can be represented in two directions: an *explanatory* and an *indicative* direction. For instance, narrative knowledge about physical causation can be represented as ‘fire causes smoke’ (explanatory) and as ‘smoke indicates fire’ (indicative). Likewise, narrative knowledge about motivational attitudes and actions can be represented as ‘jealousness motivates violence against one’s ex-partner’ (explanatory) and as ‘violence against one’s ex-partner indicates jealousy’ (indicative). The same also holds for testimonial knowledge. For example, the relation between an event and a testimony about that event can be represented as ‘John’s observation of the event made John testify that he observed it’ (explanatory) and as ‘the fact that John testified that he observed the event indicates that he observed it’ (indicative).

Choosing between these two directions is a well-known issue in AI research on knowledge representation [2,3]. Often a choice is made for a unique way to represent

¹Corresponding Author: Susan van den Braak; E-mail: susanb@cs.uu.nl.

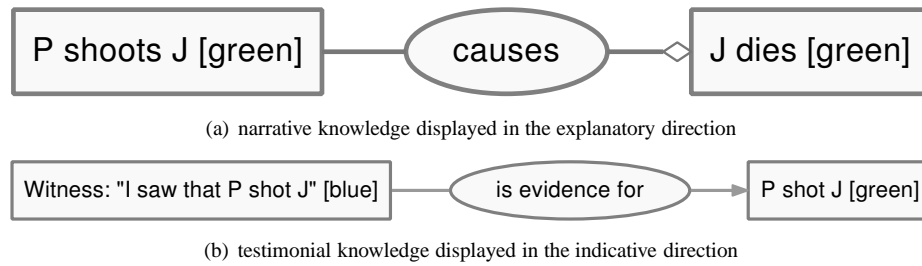


Figure 1. Narrative and testimonial information in *AVERs*

both kinds of knowledge. For example, in [3]’s application of his theorist system to a criminal case both narrative and testimonial knowledge is represented in the explanatory direction, while in [4]’s use of Wigmore charts both types are represented in the indicative direction. However, in informal contacts with Dutch crime analysts we observed that when analyzing a case they tend to prefer to represent the two kinds of knowledge in different ways. They usually represent narrative knowledge in the form of time lines of events and then hypothesize explanatory links between these events. In this way they try to construct scenarios about what might have happened in a case. Subsequently, they try to link the available testimonial evidence to the various events in the time line to express how the testimonies support or discredit these events. Thus, they use the testimonial evidence in testing the plausibility of a scenario. In line with these observations, the *AVERs* design supports the representation of the two kinds of knowledge in different directions: the explanatory direction for narrative knowledge and the indicative direction for testimonial knowledge (see Figure 1). The reasoning model underlying the narrative part is abductive inference to the best explanation while the reasoning model for the testimonial part is argumentation with argument schemes [5]. In [6] it is described how formal versions of these two reasoning models can be combined.

While there are thus good reasons for *AVERs*’ combined approach, it has not yet been tested whether this approach agrees with the intuitions of the potential users of the software. It is well-known that to be usable in practice the software’s underlying assumptions should be as natural as possible [7]. Therefore, in this paper an experiment is presented in which *AVERs*’ knowledge representation scheme was tested by users of the software. In this experiment it was investigated whether users are able to recognize and interpret both types of knowledge. Moreover, it was examined whether they have a preference for the one or the other direction to represent a certain type of information, and whether their behavior concurs with the underlying assumptions of *AVERs*.

This study consisted of two parts. In the first part, the participants had to interpret different relations and had to express their intuitions. They had to do that for graphical representations of both narrative and testimonial knowledge. We predict that if people are able to distinguish between the two types of knowledge, they will be able to correctly interpret both types of representations, but when they do not really differentiate the two types, they will confuse their interpretations. Furthermore, we expect that diagrams that are inverted, that is, in which the direction of the relation is opposite to the order proposed in *AVERs*, will be harder to interpret, but still if people are able to distinguish the two types, they will not confuse them. In the second part, the students had to express

their preference for a certain direction to represent narrative and testimonial information. We expect that they will have a preference for the indicative direction for testimonial information, while for narrative information they will prefer the explanatory direction.

This paper addresses a practical problem in the context of the development of *AVERs*, namely, that of finding a knowledge representation that is natural to crime analysts. The structure of this paper is as follows. The next section describes the experimental design. Subsequently, Sections 3 and 4 report on the results of the two parts of the study. Finally, a conclusion summarizes and discusses the results and points out topics for future research.

2. Method

The main purpose of the study was to test the validity of the assumption underlying *AVERs*. This was done by showing diagrams, as could be produced with *AVERs*, that display either narrative or testimonial information (later referred to as ‘narrative diagrams’ and ‘testimonial diagrams’ respectively). The participants were then asked to interpret these diagrams and to select their preference for a direction to express such information.

Participants 14 law students participated in a one-hour session. Additionally, 13 PhD students with a Master’s degree in law completed the questionnaire during individual sessions in their office (in total $N = 27$).

Materials and procedure The questionnaire was handed to the participants on paper and they were asked to complete all questions individually. Three versions of the questionnaire were constructed in which the order of the questions was varied. The participants were instructed to complete the questions in the order in which they were presented to them and were not allowed to glance forward or to correct previous answers. The procedure consisted of three parts. First, the participants received a brief general introduction and the aim of the experiment was described. Subsequently, the experiment started with 12 diagrams which had to be interpreted by the participants (see for more details Section 3). Note that these questions were answered without any prior instruction about the direction of relations, such that the answers reflected the participants’ true intuitions about the meaning of the displayed relations. After this part, the students were given a short explanation of the two directions in which information may be presented. Subsequently, for 27 diagrams they were asked to select the direction they preferred for the displayed information (see further Section 4).

3. Interpreting narrative and testimonial diagrams

In the first part of the experiment, six narrative and six testimonial diagrams were presented to the participants. For each type, four diagrams were in the normal direction, that is, in the explanatory direction for narrative and in the indicative direction for testimonial diagrams, while two of them were in the opposite direction. The participants were asked to write down a label which, according to them, described the nature of the displayed relation. In this way, the participants were asked to verbalize their intuitions and interpretations of the situation. Examples of all diagram types are displayed in Figure 2.

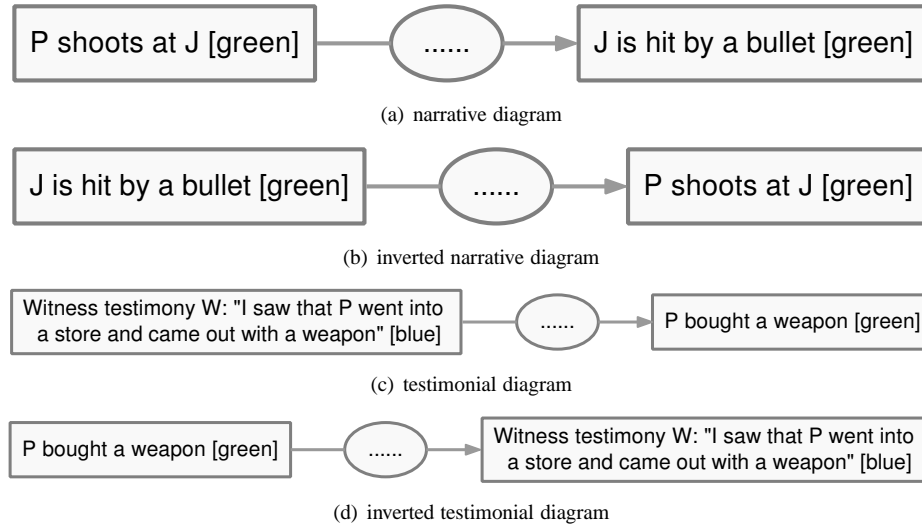


Figure 2. Examples of the diagram types that needed to be interpreted

To obtain a quantitative measure of the interpretations of the participants, the labels written down by the participants were rated along three categories, namely, explanatory, indicative, and rest. A precise description of the scheme that was used to categorize the answers is included in [8]. For all narrative and testimonial diagrams the frequencies of the labels fitting into the explanatory and indicative categories were counted. For both diagram types the maximum frequency was thus 4 per participant, since there were four diagrams per type. The inverted (narrative and testimonial) diagrams were scored in a similar matter, where for both types the maximum frequency was 2.

3.1. Hypotheses

We predicted that normal diagrams would be interpreted in their ‘correct’ direction, while inverted diagrams would be harder to interpret and were more often interpreted in the ‘wrong’ direction. More specifically, we predicted that the interpretations of narrative diagrams were in the explanatory category and those of testimonial diagrams in the indicative category. Additionally, we predicted that the inverted narrative diagrams were interpreted in the indicative category, while the inverted testimonial diagrams were interpreted in the explanatory category, but that more mistakes would be made with them.

To test this, half of the maximum frequency was taken as the test value. If a frequency equal to this value is obtained, this means that half of the labels is in the predicted group, while the other half is in the other categories. To show that at least more than half of the diagrams were interpreted in the predicted categories, the null hypothesis that the mean population frequency is equal to this test value had to be tested, so:

H_0 : There is no significant difference between the test value and the population mean ($\mu_{normal\ narrative}$ (the mean population frequency on normal narrative diagrams) = 2, $\mu_{normal\ testimonial} = 2$, $\mu_{inverted\ narrative} = 1$, and $\mu_{inverted\ testimonial} = 1$)

The alternative hypothesis, which we would like to be supported is:

H_A : The population mean frequency is significantly higher than the test value, implying that the participants give an explanatory interpretation to narrative diagrams and inverted testimonial diagrams and a indicative interpretation to testimonial and inverted narrative diagrams ($\mu_{normal\ narrative} > 2$, $\mu_{normal\ testimonial} > 2$, $\mu_{inverted\ narrative} > 1$, and $\mu_{inverted\ testimonial} > 1$).

3.2. Results

Table 1 displays the results of the summarization of the labels, produced by the participants, into the three categories per question. Note that these results are ordered according to diagram type and subsequently on frequency from high to low (the diagram with the highest number of ‘correct’ interpretations first). These results show that on the one hand, for normal narrative and inverted narrative diagrams all interpretations were in only one category (the explanatory category for normal narrative and the indicative category for inverted narrative diagrams) and that for normal testimonial diagrams all but one interpretation was indicative. On the other hand, for the inverted testimonial diagrams there was more diversity: most interpretations were explanatory, but some were indicative.

These observations are confirmed by the test results in Table 2, which shows that the mean frequency of inverted testimonial diagrams was lower than of the other diagrams. The “95% confidence interval” designates the interval which covers the true value of each

Table 1. Frequencies of the classification of the labels into the categories explanatory, indicative, and rest (the maximum frequency was 27)

Q.	Type	Description	Interpretation		
			Exp.	Ind.	Rest
b9	narrative	P shoots at $J \rightarrow J$ is hit by a bullet	24	—	3
b5	narrative	T drops a glass \rightarrow The glass is broken	23	—	4
b11	narrative	J is hit by a bullet $\rightarrow J$ is dead	23	—	4
b6	narrative	K throws the ball at $M \rightarrow M$ catches the ball	22	—	5
b4	inverted narrative (b5)	The glass is broken $\rightarrow T$ dropped the glass	—	23	4
b10	inverted narrative (b9)	J is hit by a bullet $\rightarrow P$ shoots at J	—	19	8
b7	testimonial	Witness testimony W “I saw that P went into a store and came out with a weapon” $\rightarrow P$ bought a weapon	—	23	4
b3	testimonial	Witness: “I saw a flying penguin” \rightarrow At least one penguin can fly	—	21	6
b12	testimonial	Report coroner: “This man died because of a shot wound to his head” $\rightarrow J$ died because of a head wound	1	18	8
b1	testimonial	Expert: “Penguins usually cannot fly” \rightarrow Penguins cannot fly	—	15	12
b2	inverted testimonial (b1)	Penguins cannot fly \rightarrow Expert: Penguins usually cannot fly	15	3	9
b8	inverted testimonial (b7)	P bought a weapon \rightarrow Witness testimony W “I saw that P went into a store and came out with a weapon”	15	6	6

Table 2. Mean population frequencies and results of the t -tests (the standard deviation is displayed between parentheses)

Diagram	Direction							
	Normal				Inverted			
	Mean	Test value	95% Confidence interval	p	Mean	Test value	95% Confidence interval	p
narrative	3.41 (1.08)	2	$2.98 < \mu < 3.84$	.000	1.56 (.64)	1	$1.30 < \mu < 1.81$	.000
testimonial	2.85 (1.17)	2	$2.39 < \mu < 3.31$	.001	1.11 (0.80)	1	$0.79 < \mu < 1.43$	.477
sum	6.26 (1.99)	4	$5.47 < \mu < 7.05$	.000	2.67 (1.04)	2	$2.26 < \mu < 3.08$	.003

measure with a probability of 95%. So, for instance, with a probability of 95% we can say that the true value of $\mu_{normal\ X_{narrative}}$ lies between 2.98 and 3.84 (with a mean of 3.41). This table also displays the results of the one-sample t -tests that were performed to test whether the mean population frequency was equal to the test value. For the normal diagrams and the inverted narrative diagrams, the frequencies were significantly higher than the test value. The frequency on the inverted testimonial diagrams was also higher than the test value, but this difference was not significant ($p = .48$).

On a more detailed level, the participants performed better on some questions than on others (see Table 1). These results also show that the inverted testimonial diagrams were the hardest to interpret (15 participants per question produced an explanatory label), while some of the normal testimonial diagrams were among the easiest questions. Remarkably, the participants performed quite well on the diagram “Witness testimony W : ‘I saw that P went into a store and came out with a weapon’ $\rightarrow P$ bought a weapon” ($b7$), while on its inversion ($b8$) they performed worst. Some of the participants read the inverted diagram from right to left, saying that the right box is evidence for the left box; this shows that they would prefer the diagram to be in the normal, indicative direction. The same holds for the other inverted testimonial diagram ($b2$), but to a lesser degree. For narrative diagrams the difference between normal and inverted diagrams was not that clear, as the participants performed as well on the inverted diagram “The glass is broken” \rightarrow “ T dropped the glass” ($b4$) as on its original ($b5$).

In sum, these results indicate that people are able to understand narrative diagrams in both directions, while for testimonial information the direction is important and inverting the direction may impede the understanding of the reader. At first sight this might suggest that only the indicative direction is needed to represent both types of knowledge. However, for narrative information the inversion of the direction (into the indicative direction) is not justified in cases where the cause is not the normal cause (e.g. “a smoke machine causes smoke”). Therefore, both directions are needed to correctly represent both types of knowledge.

4. Preference for directions to represent narrative and testimonial information

In the second part of the experiment, three example criminal cases were presented to the participant. Each case consisted of a short introduction, followed by four testimonial diagrams, four narrative diagrams, and one story diagram (which was a chaining of the

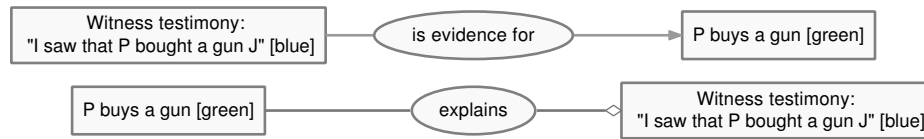


Figure 3. Example of a question where the participants had to choose a direction for testimonial knowledge

narrative diagrams). This means that there were nine ($4 + 4 + 1$) diagrams per case, so in total there were 27 (9×3) diagrams in this part of the experiment. For each case the procedure was as follows.

First, the participants received a short introduction and information about the actions taken by the police. An example is displayed below (translated from the Dutch original):

Suppose that the following events occurred. A man J was shot, the police finds P, who is acting suspiciously, near the crime scene. The police takes the following actions:

- Samples are taken from P's hands
- P is body-searched
- Witnesses are heard
- The body is examined by a coroner

Subsequently, the participants were confronted with testimonial diagrams that represented the pieces of evidence and their relation to the supported event. For every piece of evidence the relation with the event was displayed in both the explanatory and indicative direction. The participants were asked to choose the direction that they preferred (see Figure 3). Next, a possible story of the police was presented to them:

From the information found the police reconstructs what might have happened, which results in the following story: P bought a gun and shot J, J was hit in the head and died because of this.

Thereupon, narrative diagrams which displayed relations between two events of the story were presented. These relations were also displayed in both directions, and again the participants had to select their preferred direction. An example question is displayed in Figure 4. Additionally, the participants had to indicate their preferred direction for a diagram that represented the complete story.

In order to obtain a measure for the preference direction of the participants, for all narrative and all story diagrams the number of times the explanatory direction was selected was summed, while for all testimonial diagrams the number of times the indicative direction was preferred was counted. This means that for narrative and testimonial

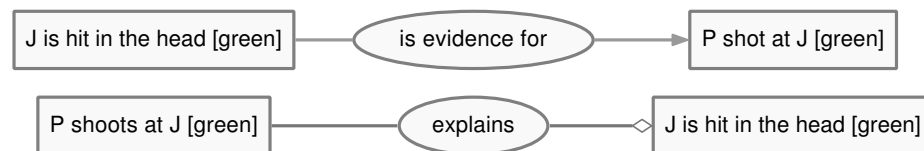


Figure 4. Example of a question where the participants had to choose a direction for narrative knowledge

diagrams the maximum frequency per participant was 12 (since there were 12 diagrams for both types) and that for story diagrams the maximum was 3.

4.1. Hypotheses

We predicted that there would be a preference for the explanatory direction for narrative and story diagrams and for the indicative direction for the testimonial diagrams, which means that the choices of the participants were not random. Now, suppose that the choice was random, then the frequencies on all diagrams would be half of their maximum (since there were only two options): this is what was used as the test value which is the value (frequency) that is expected if the participants' preference is based on randomness, that is, if there is no real preference. To disprove the claim that the choice was random, the null hypothesis that the mean population frequency is equal to this test value had to be tested, so:

H_0 : There is no significant difference between the test value and the mean population frequency ($\mu_{narrative} = 6$, $\mu_{story} = 1.5$, $\mu_{testimonial} = 6$, and $\mu_{total} = 13.5$).

The alternative hypothesis, which we would like to be supported is:

H_A : The mean population frequency is significantly higher than the test value, such that there is a preference for the explanatory direction for narrative and story diagrams ($\mu_{narrative} > 6$ and $\mu_{story} > 1.5$) and a preference for the indicative direction for testimonial diagrams ($\mu_{testimonial} > 6$ and $\mu_{total} > 13.5$).

Single sample t -tests were used to determine whether the observed frequencies were indeed different from these test values.

4.2. Results

Table 3 shows that all mean population frequencies were significantly higher than the test value. This means that for testimonial diagrams there was a preference for the indicative direction and that for narrative and story diagrams the preference was in the explanatory direction.

Also in this part there were differences between the questions (see Table 4). For most testimonial diagrams there was a clear preference for the indicative direction, but for diagram *c4* the preference was clearly in the other direction. The comments of the participants to their answers showed that the main reason for them to choose the indicative direction for testimonial diagrams was the belief that a witness testimony is a good indication for the event, but no absolute proof; the relation involves some uncertainty. This explains why for the diagram "Report medical examiner: 'This man *J* was hit in his head' \rightarrow *J* was hit in the head" (*c4*) the opposite, explanatory direction was

Table 3. Mean population frequencies and results of the t -tests

Diagram	Mean	Test value	95% Confidence interval	p
narrative	7.48 ($SD = 2.55$)	6	$6.47 < \mu < 8.49$	.003
story	2.30 ($SD = 0.91$)	1.5	$1.94 < \mu < 2.66$	.000
testimonial	9.19 ($SD = 3.11$)	6	$7.95 < \mu < 10.42$	.000
total	18.96 ($SD = 5.44$)	13.5	$16.81 < \mu < 21.11$	.000

Table 4. Frequencies of preference for the predicted direction (the maximum frequency was 27)

Q.	Type	Description	Freq.
c10	testimonial	Witness testimony: “I saw that <i>N</i> took the bike of Mrs. <i>K</i> ” <i>is evidence for N stole the bike of K</i>	25
c1	testimonial	Report laboratory: “ <i>P</i> has gunshot residue on his hands” <i>is evidence for P shot a gun</i>	23
c12	testimonial	Testimony girlfriend <i>is evidence for N stole K’s bike</i>	23
c2	testimonial	Witness testimony: “I saw that <i>P</i> bought a gun” <i>is evidence for P buys a gun</i>	22
c21	testimonial	Police file: “ <i>R</i> ’s previous convictions for selling drugs” <i>is evidence for R is involved in selling drugs</i>	22
c22	testimonial	Testimony bank: “ <i>R</i> tried to deposit large sums of money” <i>is evidence for R conducts suspicious transactions</i>	22
c19	testimonial	Excerpt BKR (Credit Information Bureau) <i>is evidence for R has debts</i>	21
c11	testimonial	Testimony girlfriend: “ <i>N</i> needed a bike, because his own bike was broken” <i>is evidence for N wanted to have a bike</i>	21
c13	testimonial	GPS signal: “The bike is in <i>N</i> ’s backyard” <i>is evidence for N put the bike in his backyard</i>	20
c20	testimonial	Telephone tap; <i>R</i> says to <i>F</i> “I need money” <i>is evidence for R needs money</i>	19
c3	testimonial	Testimony police officer: “I found a gun in <i>P</i> ’s pocket” <i>is evidence for P owns a gun</i>	18
c4	testimonial	Report coroner: “This man <i>J</i> is hit in the head” <i>is evidence for J is hit in the head</i>	12
c7	narrative	<i>P</i> shoots at <i>J</i> <i>explains J is hit in the head</i>	22
c8	narrative	<i>J</i> is hit in the head <i>explains J is dead</i>	22
c14	narrative	<i>N</i> wants to have a bike <i>explains N steals K’s bike</i>	21
c5	narrative	<i>P</i> buys a gun <i>explains P owns a gun</i>	20
c15	narrative	<i>N</i> does not have money to buy a new bike <i>explains N steals K’s bike</i>	18
c24	narrative	<i>R</i> needs money <i>explains R is selling drugs</i>	18
c26	narrative	<i>R</i> receives large sums of money <i>explains R launders money</i>	17
c23	narrative	<i>R</i> has debts <i>explains R needs money</i>	16
c25	narrative	<i>R</i> sells drugs <i>explains R receives large sums of money</i>	16
c16	narrative	<i>N</i> steals <i>K</i> ’s bike <i>explains N owns the bike</i>	13
c17	narrative	<i>N</i> owns the bike <i>explains N puts the bike in his backyard</i>	11
c6	narrative	<i>P</i> owns a gun <i>explains P shoots at J</i>	8
c18	story	Story about <i>K</i> ’s stolen bike	25
c9	story	Story about the death of <i>J</i>	19
c27	story	Story about <i>R</i> selling drugs	18

preferred, as such an expert is believed to be more credible, reliable, and objective than normal witnesses: it is perceived as being hard evidence and as a result there is no need to “keep more options open”. The same counts (but to a lesser degree) for diagram *c3*, which involves the statement of a police man. For narrative diagrams the results were more diverse: the preference for some diagrams was clearly in the explanatory direction, but for others the preference was in the opposite direction (cf. *c6*, *c17* and *c16*). This concurs with the results found on the first part of the experiment, where it was found that for narrative relations the direction is not that important.

5. Conclusion

To conclude, the analyses presented in this paper indicate that amongst law students for narrative information there is a preference for the explanatory direction and that for testimonial information the preference is in the indicative direction. The results found also suggest that they are making a conscious choice for one of the directions, based on the nature of the represented information. The data thus suggest that the underlying assumptions of *AVERs* agree with the intuitions of potential users of the system and that the proposed combined model is natural and leads to less errors on their part. However, future research has to show whether this is also the case for a larger population of participants, and in addition whether it also holds for crime analysts.

The knowledge representation of *AVERs* was tested in a way that examined only the way in which produced diagrams are read and interpreted. The study presented in this paper did not take into account the fact that one of the most important tasks of potential users of the system is to construct their own diagrams. Therefore, in future research we will let users draw diagrams and investigate whether the proposed model allows them to produce diagrams that comply with their expectations and intentions.

So, while the cognitive preferences of the potential users of sense-making tools are not studied all too often, this paper accounts for a first attempt to provide such an evaluation. It presented a method of how to conduct such research together with some preliminary results that are valuable in the light of the further development of *AVERs*.

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